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Published in:
Proceedings of EWEA 2014

Publication date:
2014

[Link back to DTU Orbit](#)

Citation (APA):
Larsén, X. G., & Kruger, A. (2014). Extreme gust wind estimation using mesoscale modeling. In *Proceedings of EWEA 2014* European Wind Energy Association (EWEA).

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Extreme gust wind estimation using mesoscale modeling

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Summary

Currently, the existing estimation of the extreme gust wind, e.g. the 50-year winds of 3 s values, in the IEC standard, is based on a statistical model to convert the 1:50-year wind values from the 10 min resolution. This statistical model assumes a Gaussian process that satisfies the classical, surface turbulence characteristics.

In this study, we follow a theory that is different from the local gust concept as described above. In this theory, the gust at the surface is non-local; it is produced by the deflection of air parcels flowing in the boundary layer and brought down to the surface through turbulent eddies. This process is modeled using the mesoscale Weather Forecasting and Research (WRF) model.

The gust at the surface is calculated as the largest winds over a layer where the averaged turbulence kinetic energy is greater than the averaged buoyancy force. The experiments have been done for Denmark and two areas in South Africa. For South Africa, the extreme gust atlases from South Africa were created from the output of the mesoscale modelling using Climate Forecasting System Reanalysis (CFSR) forcing for the period 1998 – 2010.

The extensive measurements including turbulence from the Danish site Høvsøre help us to understand the limitation of the traditional method. Good agreement was found between the extreme gust atlases for South Africa and the existing map made from a limited number of measurements across the country.

Our study supports the non-local gust theory. While the traditional method works for the surface layer, the approach used here is more suitable for higher elevations and for the application in wind energy, tall turbines.

Method

This study has been conducted in connection with the Wind Atlas of South Africa project. For two areas in South Africa, in the Eastern and Western Cape provinces, 242 storms were collected and modeled. These storms are the sum of the annual strongest storms identified at each and every CFSR surface wind grid point over the selected domains for the period 1998 – 2010, refer to [2] for the approach of storm identification over an area. The model was forced by the CFSR data, with the horizontal resolution of 36, 12 and 4 km for the three nested domains. The time step for the innermost domain is 20s, which determines the temporal resolution of our gust calculation. We used the 2.5-order turbulence closure scheme.

The approach for estimating the non-local gust was proposed by [1] in which it is argued that an air parcel will be able to reach the surface if the vertical component of the turbulence kinetic energy (TKE) is strong enough to counteract the buoyancy force. The gust at the surface is thus taken as the largest winds over the modeled levels where the averaged TKE is greater than the total buoyancy force. For each grid point, 13 annual maximum gust wind speeds are calculated.

The 50-year value is obtained afterwards using the Annual Maximum Method where the Gumbel distribution is applied.

Results

Due to the availability of both standard meteorological measurements and high frequency turbulence at Høvsøre at several levels from 10 m to 100 m, extensive data validation has been conducted here. For the storm conditions, the neutral Kaimal spectrum [3] for wind speed describes the surface wind turbulence well but underestimates the energy level at higher elevations, suggesting an enhanced height dependence of the power spectrum up to about 100 m, which levels off at higher altitudes. The local roughness length is an important contributor to the spectral energy and therefore the gust estimation. At the same time, the Gaussian process leads to overestimation of the peak factor, especially at lower levels.

The non-local gust estimation from the WRF modeling captures well the gust values measured at relatively high levels, including the magnitude and phase. This is interpreted as a support to the theory of a non-local gust.

The final atlases of the 50-year gust in South Africa are in good agreement with the map created from a limited number of measurements across the country [4].

Discussions and conclusions

The non-local concept of the gust works well for relatively high elevations of about 100 m, where the uncertainty of the traditional method is the highest. However, this non-local gust concept does not consider the local surface effect. The actual variation of the gust in the surface layer reflects the fact that if the estimation should be used at the very low level, a combination or merge of the traditional method and this non-local method should be considered.

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